RESEARCHES IN RADIO TELEPHONY

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Researches in Radio Telephony

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RESEARCHES IN RADIO TELEPHONY

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RESEARCHES IN RADIO TELEPHONY

Object

In the last few years the strides in radio telephony have been very rapid. About ten years ago the scientific world was first introduced to the fact that radio telephony was possible; but for the first few years following, the progress in this branch was comparatively slow due to the difficulties in the generation of high frequency currents of the undamped wave type. The only two ways it was found possible to generate currents of this nature was by the arc generator or by the high frequency generator; but in the last six or seven years a new type of generator has come into existance; namely, "The Hot Cathode Vacuum Tube". This generator practically revolutionized the entire field of radio telephony and to a lesser extent radio telegraphy; but had it not been for the war, it is rather doubtful whether our advance in this science in the last four years would have been quite as rapid as it has been.

The difficulties encountered in radio telephony are several:

1. The modulation of large amounts of power by the human voice.

2. The modulation of these currents without distortion.

3. Increasing the selectivity to such an extent that in a city of a large population it could be used as a means of intercommunication just as wire telephony today.

4. Simplifying the apparatus so that the users of these telephones would not have to be experts to operate them after they are once in operation.

In the following discussion the first two of the four difficulties given will be considered; namely,

1. The modulation of high amounts of power by the human voice; and

2. The modulation of these currents without distortion.

As a preliminary to the following Articles there are two rather interesting and necessary subjects to be discussed:

1. The use of a three element tube as a rectifier.

2. Compensating for the losses in the tube by means of a three element tube used as a dynatron.

These two matter will be taken up in chapters I and II.

Before going into chapters I and II let me express my sincere thanks and appreciation to Professor Guy Maurice Wilcox who so willingly cooperated with me in some parts of the following investigations.

RESEARCHES IN RADIO TELEPHONY

Part I

Chapter I

The Developement and Use of the Kenotron.

The developement of the vacuum tube has been extremely rapid in the last few years and with this developement came a new type of radio frequency generator; namely, the hot cathode vacuum rectifier.

It is a well-established fact that if a heating element is enclosed in a vacuum and heated to incandescence that there is a thermionic radiation in all directions. This can be, and has been definitely established by putting a plate around the filament and connecting this in series with a milliammeter and high voltage battery of about 30 volts to the negative side of the battery or source of supply which is used for heating the filament to incandescence.

It has been found that this radiation consists of negative electrons and that the number of electrons emitted increases very fast as the

temperature of the hot cathode increases until a point of saturation is reached. This point is determined by the dimensions of the tube.

If the plate is kept at a positive potential these electrons emitted will be drawn towards the plate and a current will be set up in this plate circuit. See Figure 2. The current in this circuit will be found to vary as the voltage and can be expressed by the following equation:

$$i = 14.65(10^{-6}) \ \frac{L}{r} \ e^{\frac{3}{2}}$$

where

i = The current in the plate circuit in amperes.

L = The length of the filament in centimeters.

r = The radius of the cylinder.

Mr. Saul Dushman of the General Electric Company found that the ionic discharge from the hot cathode increased from about .14 ampere per square centimeter at 2,300° absolute to .36 amperes at 2,400° to .89 amperes at 2,500 and to 2.04 amperes at 2,600°; but at high temperatures the filament

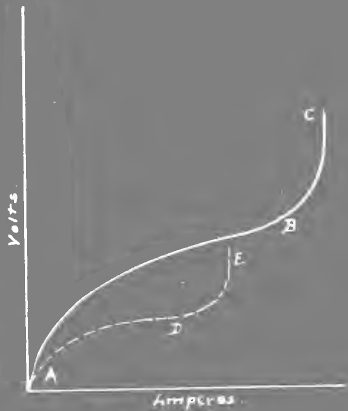


Fig 1.

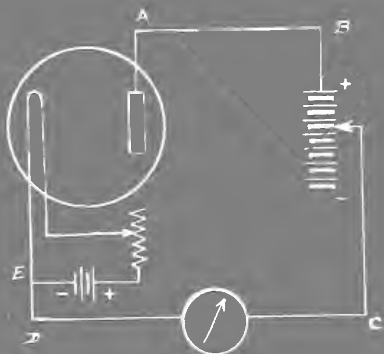


Fig 2.

deterioration is quite rapid.

Some idea of the rapidity of increase of the current as the voltage is increased can be gotten by looking at Figure 1. The current from A to B conforms very closely with the curve gotten by plotting the above equation for different values of e; when L and r are some definite values which are kept constant as e is varied.

The dotted curve A, D, E, F is the curve for a lower filament current and consequently a lower filament temperature.

There is also another current limitation which may prove very serious in practice in high vacuum tubes. This is the so-called space charge and depends on the following considerations. If the plate voltage has a given value, increase of filament temperature will increase the plate current to a point B, Figure 3, but no futher. This is due to the following effect: The cloud of negative electrons surrounding the filament at any time acts as a large negative charge in its neighborhood, and consequently repels all electrons which are, or tend to be emitted by the filament, thus choking back

the electron current stream. If the charge in the space surrounding the filament becomes sufficiently great, no increase in temperature at a given voltage will produce any further current. Either the plate voltage must be increased or the bulb construction altered so as to diminish the space charge. Bringing the plate and filament close to each other will diminish the space charge effect. The effect is indicated at B in Figure 3; and for a lower applied plate voltage, at D with the dashed line.

In the course of Dr. S. Dushman's investigations, he states that the safe current-carrying capacity of vacuum tube rectifiers, are as follows. For a filament .005 inches (.012 cm.) in diameter, .03 amperes can safely be emitted per centimeter of length and that under these conditions the filament heating current will represent 3.1 watts of power per centimeter of length. For filaments .01 inches in diameter (.025 cms.) the safe current is .10 ampere and the power is 7.2 watts per unit of length. From this, some indication can be gotten of what may be expected from tubes of ordinary dimensions based on these thermionic currents. Langmuir states that

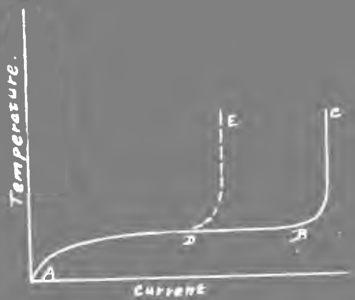


Fig 3

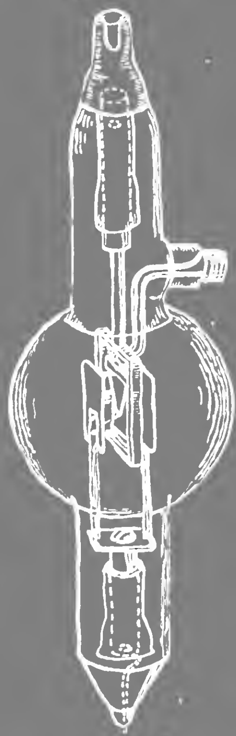


Fig 4

the type of tube developed by Dr. Irving Langmuir and Dr. Saul Dushman, together with William C. White of the General Electric Company has a capacity of 250 milliamperes and can be used with voltages as low as 200 and as high as 50,000 volts. The efficiency is stated as 97.8%. Figure 4 is a diagram of this bulb. If a greater current than this is to be rectified, he states it is better and more efficient to connect more bulbs in parallel and probably just as economical as using a larger bulb.

In connection with the developement of these tubes a curious effect was encountered when the joint filament heating and thermionic (pure electron) currents were combined. In the filament heating curcuit shown in Figure 5, the current circulates in the direction indicated by the dotted arrows. Therefore, under normal conditions, the ammeters A_1 and A_2 read the same. If, however, the plate circuit is closed, and a current indicated by A_3 appears in that circuit, its direction of flow will be as indicated by the full line arrows. (I suppose it is understood that the direction of flow of the current is opposite to that of the negative

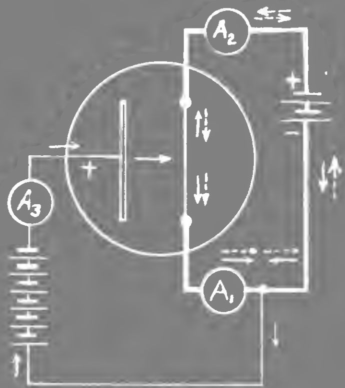


Fig 5

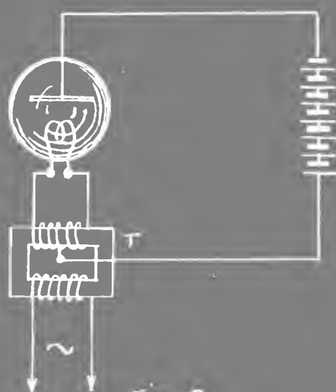


Fig 6

electrons, in accordance with the commonly accepted convention). When this current appears in A_3 it will be noticed that the plate current A_3 will flow outward from both ends of the filament. Consequently, at the lower end it will assist the lighting current, while at the top it will oppose it. So that, if A is the true lighting current, the readings of the ammeters will be given by $A_1 = A + A_3$ and $A_2 = A - A_3$. With small tubes, such as used for receiving, this effect is of no practical importance, but when larger tubes passing heavier plate currents are used it may become serious if the filament is already worked near the burn-out point.

Mr. William C. White, to whom much of the recent developements of the Pliotron is due, ingeniously minimized this effect by connecting that part of the circuit as shown in Figure 6.

It must be remembered that this entire discussion assumes that the vacua in these tubes are practically perfect (within a few ten millionths part of a millimeter of mercury) and that the electrodes and

walls of the tube have been freed from any occluded gasses while the tube was being exhausted. This is a condition that is hard to obtain and hard to maintain, consequently slight variations will occur in the results obtained by different bulbs. A full discussion on this subject can be obtained by consulting Dr. Langmuir's paper appearing in the September issue of the "Proceedings of The Institute of Radio Engineers for 1915".

Alternating current rectifiers, manufactured by the General Electric Company, are on the market both for high and low voltages. The low voltage bulbs, sold under the name of Tungar rectifiers, are constructed for voltages up to about 150 volts and the Kenotron for voltages from 150 to 100,000 volts.

RESEARCHES IN RADIO TELEPHONY

Part I

Chapter II

The Use of a VT_2 as a Kenotron for High Voltage Rectification

The VT_2, as this bulb is called by the Signal Corps, is manufactured by the Western Electric Company, and is intended to be used as a generator of high frequency currents. The filament of this bulb is designed to operate on 1.3 amperes when in normal operation and with this current has a life of approximately 1000 hours. The filament is made of lime-coated platinum and for this reason requires such a small filament current. The grid is composed of a number of turns of tungsten wire, spaced equally on either side of the filament. The plates are made of sheet nickel about ½" x 1" placed on either side of the grid and is placed far enough away to withstand a voltage of 300 under normal operation. With this plate voltage and normal filament current the output in the grid circuit is about 100 milliamperes, and in the plate circuit is about 150 milliamperes.

Figure 9 shows the arrangement of the filament, grid and plate in this type of vacuum valve and Figures 10-11 show the characteristic curves as a two element and three element bulb.

In the test carried on with the type of bulb described above we found that the bulb is designed to withstand an overload of about 200% without breaking down and if care is taken the plate voltage can be run up to 750 without disasterous results. At this voltage or above the bulb suddenly breaks down, that is, sparking occurs between the plate and filament without the characteristic blue glow which ordinarily occurs before breakdown between conductors. This test was made using an alternating current of 36 cycles in the plate circuit. The filament was heated by direct current supplied by storage batteries.

It was found that although the bulb rectified as good as a regular Kenotron, the direct current voltage was too low to be of any value for the purpose in mind. This was because the bulb, although able to stand a fairly high voltage

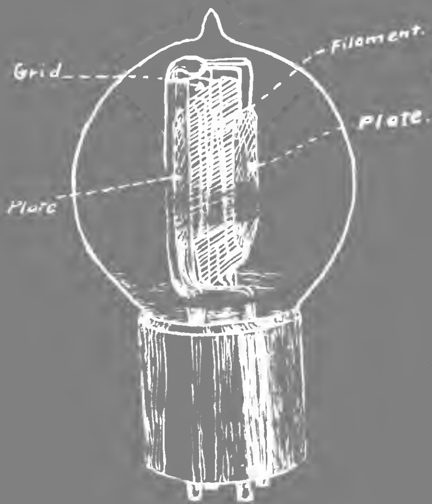


Fig 9

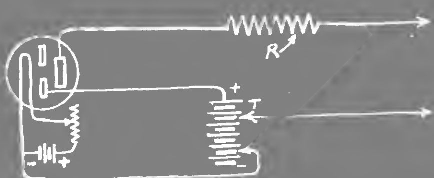


Fig 12

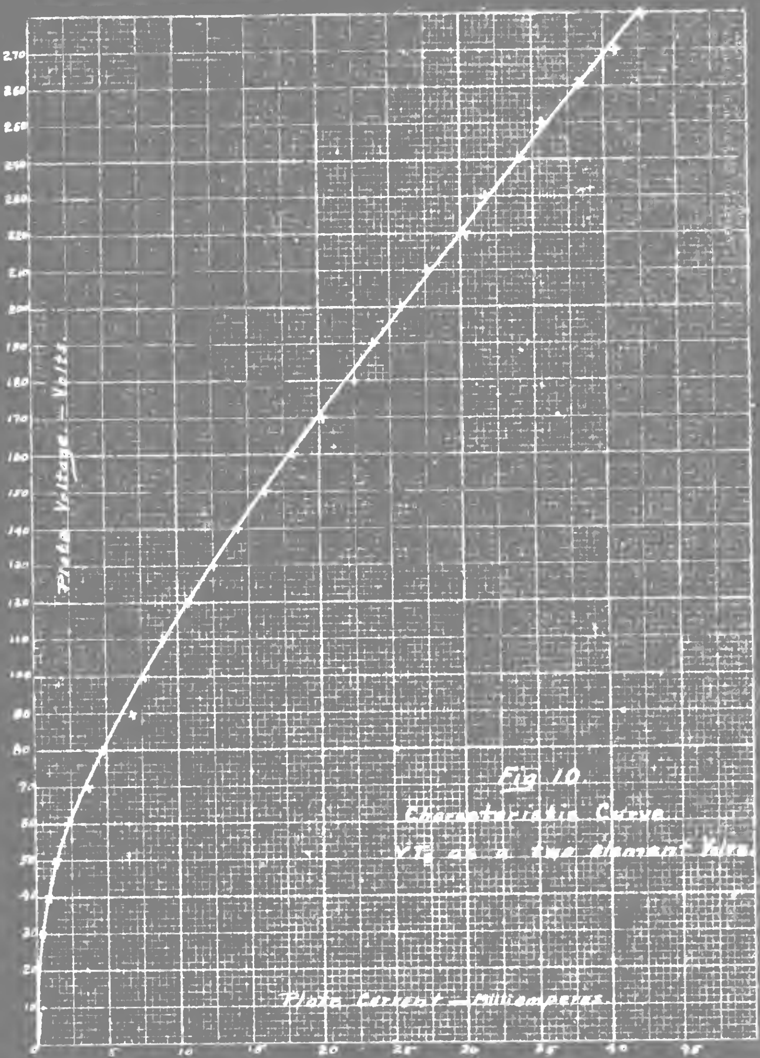


Fig 10.
Characteristic Curve
VT as a two element Valve.

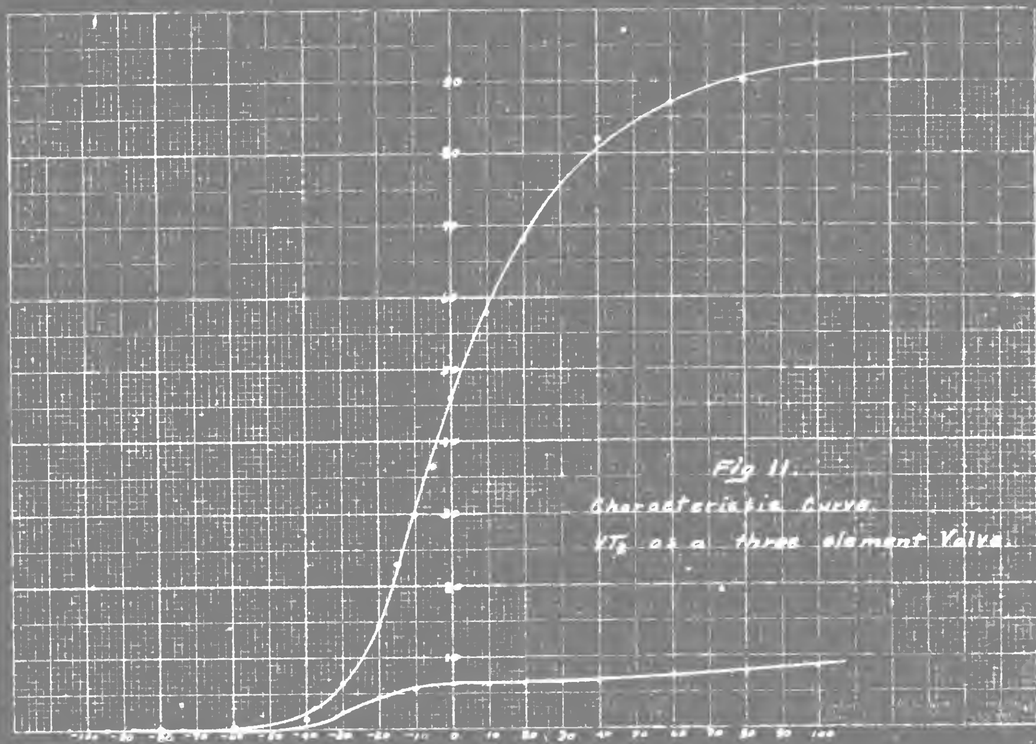
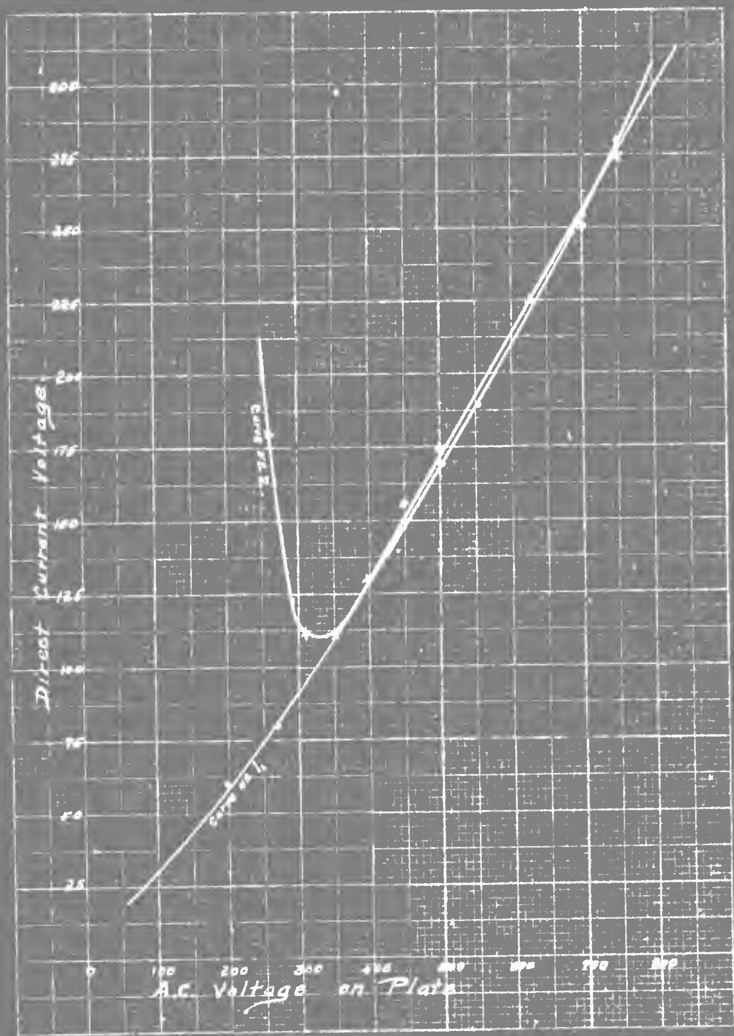


Fig 11.

Characteristic Curve.

VT_2 as a three element Valve.



Direct Current Voltage
A.C. Voltage on Plate
Curve No. 1
Curve No. 2
25
50
75
100
125
150
175
200
225
250
275
300
0
100
200
300
400

VT_2 Rectifier Data.

	Alternating Current				Direct Current.						
	W_1	A_1	V_1	F_1	A_A	A_B	V_A	V_B	V_L	A_L	V_D
	Watts	Amperes	volts	Alt	Amperes	Amperes	Volts	Volts	Volts	Milliam	Volts
1	0	0	260	72	1.0	1.0	4.7	4.3	180	.00	80.
2	1.5	0	318	72	1.0	1.0	4.7	4.3	114	.00	196.
3	1.0	.5	350	72	1.0	1.0	4.7	4.3	110	.05	240.
4	1.5	.5	400	72	1.0	1.0	4.7	4.3	130	.05	270.
5	1.8	.5	450	72	1.0	1.0	4.7	4.3	156	.05	294.
6	2.0	.5	500	72	1.0	1.0	4.7	4.3	175	.05	325.
7	2.5	.5	628	72	1.0	1.0	4.7	4.3	225	.05	400.
8	4.0	.5	700	72	1.0	1.0	4.7	4.3	250.5	.05	449.5
9	6.0	.5	750	72	1.0	1.0	4.7	4.3	275.0	.05	475.0
10	0.0	.5	100	72	1.25	1.25	6.35	6.00	30.5	.05	69.5
11	0.0	.5	200	72	1.25	1.25	6.35	6.00	60.5	.05	139.5
12	.5	.5	270	72	1.25	1.25	6.35	6.00	80.5	.05	189.5
13	.6	.5	350	72	1.25	1.25	6.35	6.00	110.5	.05	239.5
14	1.5	.5	400	72	1.25	1.25	6.35	6.00	130.0	.05	270.0
15	2.0	.5	450	72	1.25	1.25	6.35	6.00	150.0	.05	300.0
16	2.2	.5	500	72	1.25	1.25	6.35	6.00	170.0	.05	330.0
17	2.3	.5	550	72	1.25	1.25	6.35	6.00	190.0	.05	360.
18	2.5	.5	628	72	1.25	1.25	6.35	6.00	225	.05	403.
19	2.5	.5	700	72	1.25	1.25	6.35	6.00	255	.05	445.
20	2.5	.5	750	72	1.25	1.25	6.35	6.00	280	.05	470.

would not stand voltages in the neighborhood of 1,500 to 3,000 volts. The VT_1 and the bulbs of the General Electric Company were also tried, but would not stand voltages as high as the VT_2, so no data will be given on these; but the data taken on the VT_2 will be found on the following page.

Figure 7 gives a scheme of connections used by the General Electric Company in the course of their investigations. It will be seen that the generator is connected to a transformer containing two double secondaries, S_1 and S_2. These might be called single secondaries with a lead brought out from the middle point. The secondary S_1 is designed to supply the filament lighting current, while the secondary S_2 is designed to supply the plate of each Kenotron with the high voltage it is to rectify. The ends of this secondary are connected to the plate of each Kenotron and the middle tap is connected in series with a condenser of several microfarads to the middle tap of the lighting secondary. The load is taken

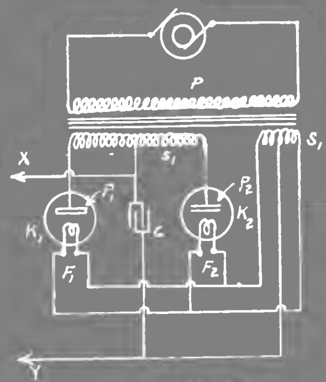


Fig 7

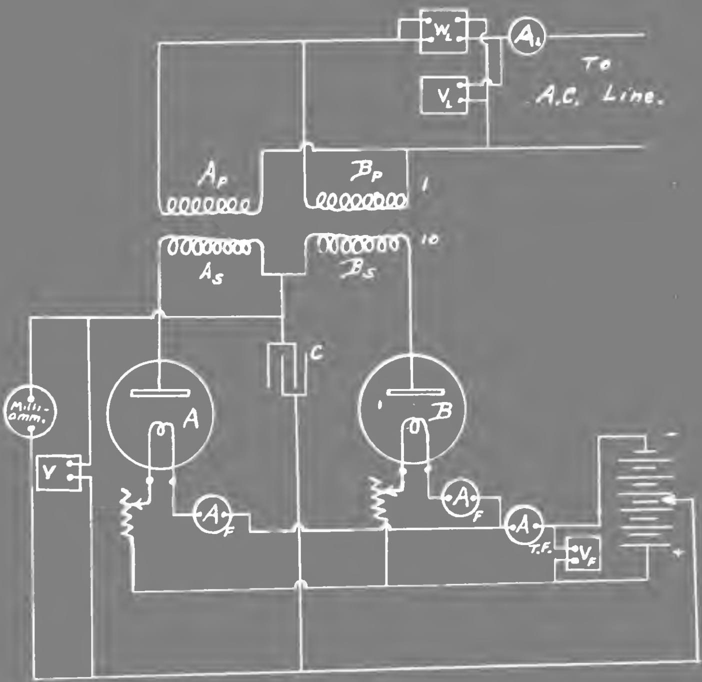


Fig 8

off from each side of the condenser c, as X and Y, as shown. The purpose of this condenser is to eliminate as far as possible the ripples in the rectified alternating current.

The purpose of the middle tap on the lighting secondary has already been explained in the previous chapter.

Curve No. 1.

A. C. to D. C. Voltage for 1.25 ampere filament current.

Curve No. 2.

A. C. to D. C. Voltage for 1.00 ampere filament current.

Figure 8 is a scheme of connections used in testing the use of a VT_2 as a Kenotron.

RESEARCHES IN RADIO TELEPHONY

Part II

Chapter I

Construction and Use of the Dynatron.

The dynatron is another member of the family of hot cathode devices, which have been developed at the Research Laboratory of the General Electric Company by Mr. A. W. Hull, Ph.D.

In construction, this bulb resembles the Kenotron and Pliotron, or ordinary three element vacuum valve, but in the principles of operation these bulbs are entirely different.

1. The Three Element Vacuum valve utilizes the principle of controlling, by means of the grid, the space charge due to the thermionic current flowing from the filament to the plate.

2. The Kenotron utilizes the uni-directional property of thermionic current flowing from the filament to the plate.

3. The Dynatron utilizes the secondary emission of electrons by a plate upon which the primary electrons fall. This bulb, as its name

indicates, is a generator of electric power, and feeds energy into any circuit to which it is connected. It is like a series generator, in that its voltage is proportional to the current thru it, but it is entirely free from the hysteresis and lag that are inherent in Generators and in all devices which depend upon gaseous ionization.

The dynatron consists of a heating element placed inside of an evacuated tube with a perforated plate called the anode and a third element called a plate. The anode is perforated so that, as the filament is heated to incandescence the velocity of the electron stream is not hindered on its way to the plate. The velocity of these electrons is quite high if the plate potential is high and on striking the plate, cause secondary electrons to be ejected from it. These electrons are ejected with a velocity sufficient to cause them to strike the anode, or at least come in close vicinity to the anode, which is between the plate and the filament, and as the anode is kept at a positive potential the electrons are attracted to

it and a current is caused to flow in any circuit connected to the anode and the battery as shown in Figure 12.

If the potential on the plate is low the velocity of the electron stream is low and no electrons will be ejected upon hitting the plate and therefore a current is caused to flow in the plate circuit. But if this plate potential is raised, less current flows in this circuit until finally we have a current flowing from the plate to the anode instead of from the filament to the plate. When this condition exists the bulb is said to have negative resistance or in other words it becomes a generator of electrical energy.

Figure 13 shows a characteristic curve of a dynatron connected as shown in Figure 12. The portion from A_o to C_o is termed the negative resistance portion of the curve. If we let $\bar{r}$ be the bulb impedance which is negative and I the current thru the bulb, then we have

$$e_2 = I \bar{r}$$

If a resistance is put into the circuit and we let $\bar{r}$ equal the resistance of the external resistance

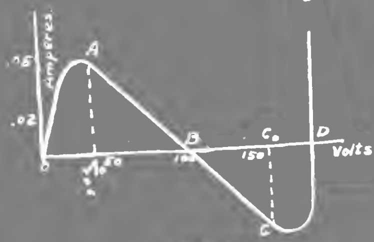


Fig 13

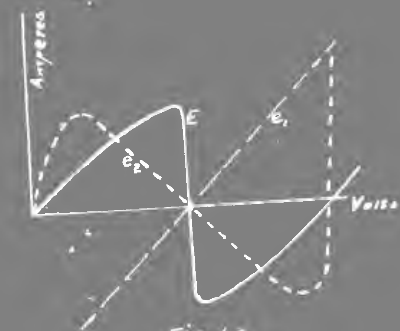


Fig 14.

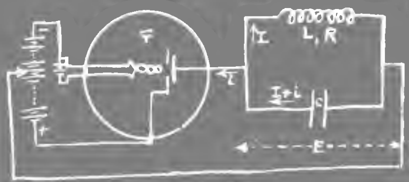


Fig 15.

and I the same current as that through the bulb. Then

$$e_1 = IR$$

Combining the two, we obtain

$$e_1 + e_2 = I\,(\bar{r} + R)$$

but $e_1 + e_2$ equals the total voltage across the combination, therefore we can put $(e_1 + e_2)$ equal to E and then

$$E = I\,(\bar{r} + R)$$

And the voltage amplification equals

$$\frac{e_1}{E} = \frac{R}{\bar{r} + R}$$

When the dynatron is connected in series with a circuit containing resistance, inductance and capacity as in Figure 15 we get as the mathamatical solution:

$$\frac{d^2 I}{d t^2} + \left(\frac{R}{L} + \frac{1}{\bar{r}C}\right)\frac{dI}{dt} + \frac{1}{LC}\left(1 + \frac{R}{\bar{r}}\right) I + \frac{i_0}{LC\bar{r}} = 0$$

which reduces to,

$$1.\quad I = \frac{i_0}{R + \bar{r}} + A\epsilon^{-\frac{1}{2}\left(\frac{R}{L} + \frac{1}{\bar{r}C}\right)t} \cos\left(\sqrt{\frac{1}{LC} - \left(\frac{R}{2L} - \frac{1}{2\bar{r}C}\right)^2}\, t - a\right)$$

if $\left(\frac{R}{L} - \frac{1}{\bar{r}C}\right)^2 - \frac{4}{LC} < 0.$

And

$$2.\ I = -\frac{i_o}{R+\bar{r}} + A\epsilon^{\left[-\left(\frac{R}{2C} + \frac{1}{2\bar{r}C}\right) + \sqrt{\left(\frac{R}{2C} - \frac{1}{2\bar{r}C}\right)^2 - \frac{1}{LC}}\right]t}$$

$$+ B\epsilon^{\left[-\frac{R}{2L} + \frac{1}{2\bar{r}C}) - \sqrt{\left(\frac{R}{2L} - \frac{1}{2\bar{r}C}\right)^2 - \frac{1}{LC}}\right]t}$$

if $\left(\frac{R}{L} - \frac{1}{\bar{r}C}\right)^2 - \frac{4}{LC} > 0$

Where i_o, A, α are constants, and R is the external resistance; $\bar{r}$ is the negative resistance of the bulb; L is the inductance; c is the capacity and ϵ is the base of the natural logarithm.

In the oscillatory solution; given by equation 1, the most interesting fact is noticed that this solution differs from that of a simple oscillatory circuit, in that the damping factor is decreased from $\frac{R}{2L}$ to $\frac{R}{2L} - \frac{1}{2rc}$, in which r represents the positive numerical value of $\bar{r}$, and the period is increased by increasing the damping correction from $(\frac{R}{2L})^2$ to $(\frac{R}{2L} - \frac{1}{2rc})^2$. This is the same as a circuit containing a leaky condenser, the positive charge resistance of the condenser being replaced by the negative resistance $\bar{r}$ of the dynatron.

A complete treatment of this subject is beyond the scope of this paper; but as the reader will find a very complete discussion of the Dynatron in the "Proceedings of Radio Engineers for February, 1918,(Vol. 6, No. 1)", no more space will be taken up here.

Figure 14 shows the characteristics of a dynatron when the external resistance is equal to the bulb impedance.

RESEARCHES IN RADIO TELEPHONY

Part II

Chapter II

The Use of a VT_2 as a Dynatron

The VT_2, which has already been described in chapter II of Part I; does not work very satisfactorily as a dynatron. This is probably due to a relative large spacing between the three elements composing the tube, and, due to a lesser extent to the coarse grid that is used in the construction of the VT_2, and because of this coarse grid being used, the decrease in surface area exposed to the ionic current flowing from the plate to the grid when high potentials are used on the plate, is not as great as if the grid were of finer construction and, therefore, the characteristics of the tube would be different.

One interesting fact that is noticed on the graph following this page is that if dotted lines are drawn thru the points of the same filament temperature that these curves will be as the dotted curves shown on the graph and seem to follow some definite law. Whether this, is just due to some

peculiar condition of the circuit, or, is one of the characteristic properties of the bulb can not be definitely stated.

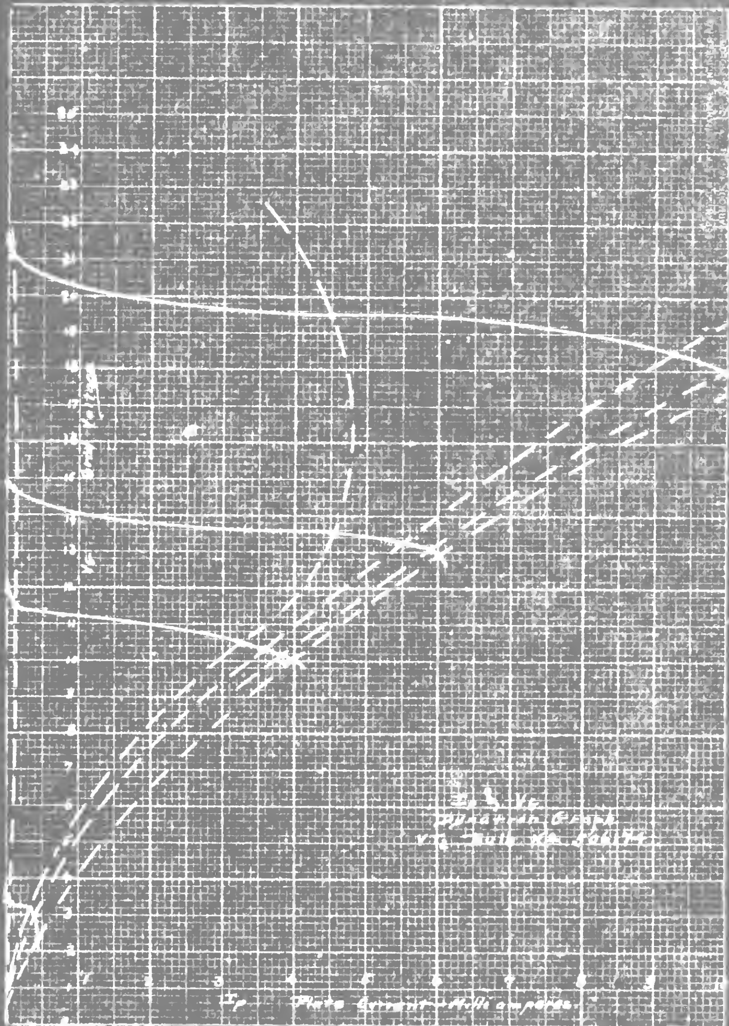
This seems only to be true if low voltages are used because readings takent at higher voltages do not conform with those taken at the lower voltages. This might be due to the fact that a coated filament is used and when high voltages are used on the plate the characteristics of the bulb changes. In any case its action as a dynatron is not satisfactory.

VT_2 Dynatron Data.

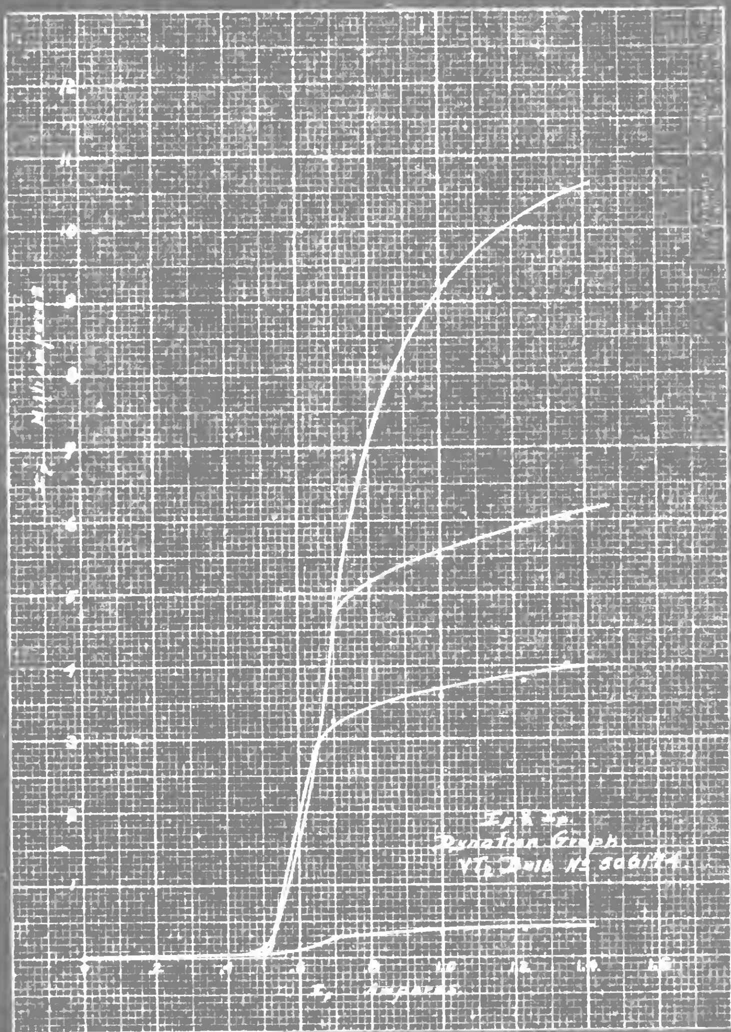
I_F	0	.1	.25	.50	.60	75	.85	1.00	1.25	1.35	Amps.
V_G	20	20	19.98	19.96	19.94	19.5	19.0	18.5	18.25	18.1	Volts
I_P	0	0	.01	.09	.49	3.4	7.6	12.5	13.0	13.5	Milliamp.
V_G	30	30	29.95	29.85	29.8	29.5	29.1	28.9	27.2	26.8	
I_P	0	0	.01	.125	.45	3.5	8.45	22.5	27.5	28.0	
V_G	40	40	39.95	39.95	39.95	39.95	39.9	39.8	39.7	39.5	
I_P	0	0	.01	.025	.34	3.1	9.25	31.5	51.5	53.	
V_G	50	50	50	49.95	49.8	49.5	48.6	46.4	42.7	42.5	
I_P	0	0	0	.01	.35	3.25	10.0	25.75	55.4	55.75	
V_G	60	60	59.95	59.94	59.9	59.8	59.2	56.8	51.9	51.5	
I_P	0	0	.01	.06	.30	3.0	7.8	25.8	75.0	76.0	
V_G	70	70	69.95	69.9	69.6	69.5	69.5	68.6	64.5	63.5	
I_P	0	0	.01	.07	.27	2.5	7.25	25.5	95	108	
V_G	80	80	80	79.95	79.85	79.9	79.4	77.0	68	65.9	
I_P	0	0	.01	.05	.15	1.86	6.0	25.2	95.5	11.8	
V_G	90	90	89.95	89.95	89.9	89.85	89.5	87.5	79.5	76.0	
I_P	0	0	.01	.05	.15	1.75	5.57	25.0	107.5	137.0	
V_G	100	100	99.95	99.85	99.8	99.8	99.4	98.0	92.4	89.0	
I_P	0	0	.01	.05	.17	1.55	5.60	24.5	115.0	157.5	
V_G	110	110	110	109.95	109.9	109.85	109.8	109.0	104.5	102.4	
I_P	0	0	.01	.07	.18	1.55	5.45	25.0	122.2	177.5	

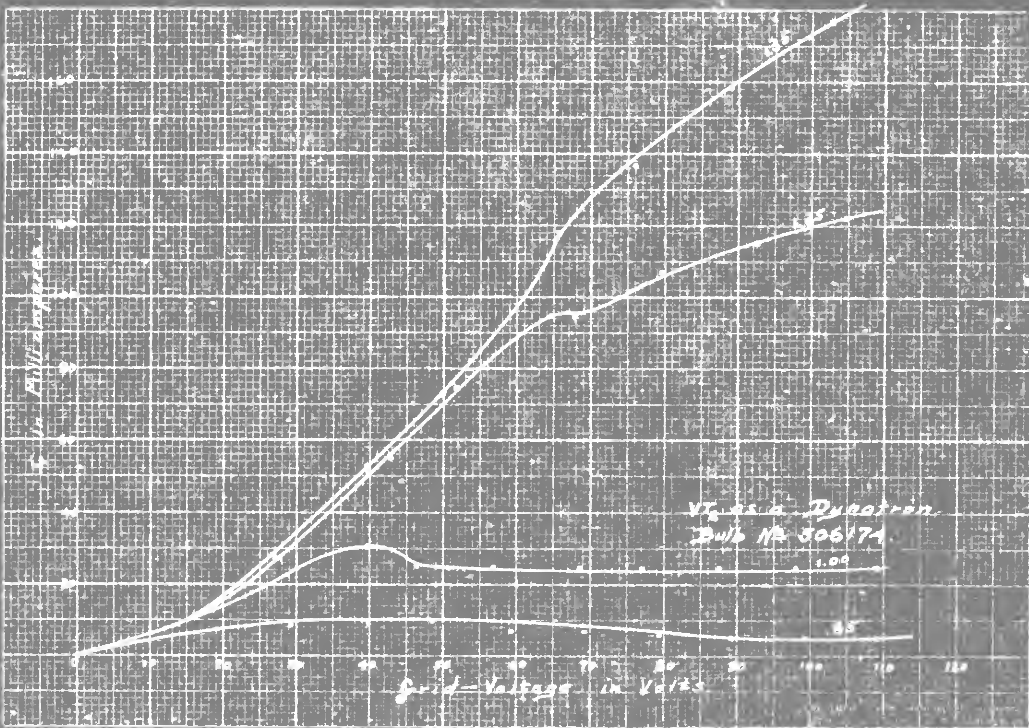
VT2 Dynatron Data.

	V_G	I_P	I_F
1.	21.5	0	0
2.	21.0	.08	.5
3.	19.5	5.00	.75
4.	18.5	9.25	1.00
5.	18.0	10.00	1.25
6.	17.75	10.50	1.35
7	14.80	0	0
8.	14.75	.10	.5
9.	13.55	4.55	.75
10.	13.20	5.50	1.00
11.	13.10	5.90	1.25
12.	12.95	6.00	1.35
13	11.85	0	0
14	11.50	.125	.5
16	10.55	3.25	.75
16	10.35	3.60	1.00
17	10.20	3.80	1.25
18	10.10	4.00	1.35
19	3.40	0	0
20	3.35	.09	.5
21.	3.32	.29	.75
22.	3.30	.35	1.00
23.	3.00	.39	1.25
24.	2.28	.425	1.35



Dynatron Graph
Plate Current – Milli amperes


Milliamperes
Ionization Graph
Amperes



VT₂ as a Dynatron
Bulb No 306174
1.00
Grid-Voltage in Volts
i in Milliamperes

RESEARCHES IN RADIO TELEPHONY

Part II

Chapter III

The Use of a VT_1 as a Dynatron

The VT_1, as this bulb is called by the Signal Corps, is manufactured by the Western Electric Company, and is intended and was designed to be used as a receiving bulb.

The filament of this bulb is designed to operate on 1.1 amperes at 3.8 volts when in normal operation and with this current in the filament circuit, it has a life of about the same length of time as that of the VT_2. The grid is composed of a larger number of turns of tungsten wire than in the VT_2, but a finer weave is used and are spaced equally on either side of the grid. The normal voltage to be used on the plate is around 20 volts.

Tests with the bulb used as a dynatron showed little better results than those for the VT_2 just as would be expected from the fact that

VT_1 Dynatron Data.

	I_P	V_P	I_G	V_G	I_F
1	0	0	0	0	.5
2	2.9	4.3	0	10	.5
3	2.85	4.3	0	20	.5
4	2.85	4.3	0	30	.5
5	2.85	4.3	0	40	.5
6	2.85	4.3	0	50	.5
7	2.85	4.3	0	60	.5
8	2.85	4.3	0	70	.5
9	2.85	4.3	0	80	.5
10	2.85	4.3	0	90	.5
11	2.85	4.3	0	100	.5
12	2.85	4.3	0	110	.5

	I_P	V_P	I_G	V_G	I_F
1	4.9	4.28	2.75	10.0	1.0
2	5.2	4.28	3.10	10.0	1.25
3	5.25	4.28	3.25	10.0	1.40
4	4.88	7.20	0	10.0	.5
5	7.70	7.20	2.0	10.0	1.0
6	8.30	7.20	2.50	10.0	1.25
7	8.30	7.20	2.60	10.0	1.40
8	6.67	9.9	0	10.0	.5
9	13.00	9.9	1.5	10.0	1.0
10	13.70	9.85	1.9	10.0	1.25
11	13.70	9.85	2.0	10.0	1.40
12	8.35	12.65	0	10.0	.5
13	15.00	12.65	1.15	10.0	1.00
14	16.50	12.60	1.50	10.0	1.25
15	16.5	12.60	1.60	10.0	1.40
16	1.1	16.00	0	10.0	.5
17	6.4	15.50	1.00	10.0	1.00
18	7.4	15.70	1.30	10.0	1.25
19	7.6	15.70	1.35	10.0	1.40
20	1.45	21.0	0	10.0	.5
21	7.10	19.50	1.70	10.0	1.00
22	8.25	19.0	2.00	10.0	1.25
23	8.45	19.0	2.10	10.0	1.40

the spacing of the three elements are closer together and a grid with a finer mesh is used. But this, as in the previous tests held only for low voltages. When comparative high voltages were used the characteristics changed just as in the VT_2, probably on account of the coated filament.

If the grid that is in this bulb were removed and one of a very fine mesh substituted, it would probably work still better.

Tests were made on the VT_{13}, manufactured by the General Electric Comapny, and fairly good results were obtained, but not sufficient data were taken with this tube to make any definite statement.

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